The potential impact of the Large Earth Bumblebee *Bombus terrestris* (Apidae) on the Australian mainland: Lessons from Tasmania

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Abstract

The Large Earth Bumblebee *Bombus terrestris* (L.) (Hymenoptera: Apidae) is an invasive species that has not yet established on the Australian mainland. However, a feral population was discovered in Tasmania in 1992 and applications have been made to import the species to the Australian mainland for pollination of crops inside greenhouses. The introduction of *B. terrestris* to the Australian mainland for pollination of greenhouse crops poses a potential threat to Australia's biodiversity because: (1) *B. terrestris* is likely to escape from captivity and form feral populations in the wild across a large area; (2) *B. terrestris* forages on many species of native and introduced plants and has spread rapidly throughout all major native vegetation types in Tasmania; (3) *B. terrestris* is able to reduce the amounts of nectar available to other animals by foraging at lower temperatures than other bees; and (4) the effectiveness of *B. terrestris* as a pollinator sometimes differs from that of other animals. Recent research suggests that *B. terrestris* is reducing reproductive success in an endangered species of bird in Tasmania by reducing nectar availability, and several species of introduced plants have become more invasive in Tasmania since *B. terrestris* arrived there. (*The Victorian Naturalist* **124** (1) 2007, 110-117)

Introduction

The Large Earth Bumblebee *Bombus terrestris* (L.) (Hymenoptera: Apidae) is an invasive species that has not yet established itself on the Australian mainland, but has been present in Tasmania since 1992 (Semmens *et al.* 1993). Concern about the potential for its establishment on mainland Australia has already led to *B. terrestris* being listed as a threatening process in both Victoria and New South Wales (Lefoe and Backholer 2002;Whelan *et al.* 2004). It is, therefore, important for people living on the Australian mainland to become familiar with *B. terrestris,* and its potential impacts, to maximize the chances of any founder populations being reported as soon as possible to relevant government agencies. Early detection provides the best chance of preventing *B. terrestris* from establishing feral populations on the Australian mainland.

Bombus terrestris is a heavily-built, hairy bee with broad black and golden-yellow bands. It varies greatly in size, with body lengths ranging from 8 mm up to 35 mm. The larger individuals make a loud buzzing sound and are often heard before they are seen. This species has annual colonies in pre-existing cavities in or near the ground and comprises three castes. Queens are the largest caste and these establish the colonies on their own after having mated with a drone. The queen collects nectar and pollen from flowers to feed her first batch of larvae which develop into workers. The adult workers then take over the role of collecting food to feed subsequent batches of larvae and the colony grows in size until worker production is replaced by production of new queens and drones. After worker production ceases the adult workers gradually die off and, with the decline of numbers of bees collecting nectar and pollen, the colony and original queen eventually die out. The new queens then mate with drones and establish new colonies (Cumber 1953; Donovan and Macfarlane 1984; O'Toole and Raw 1991; Prys-Jones and Corbet 1991).

Bombus terrestris is currently expanding its range across the world because of human assistance. The natural distribution of *B. terrestris* encompasses most of Europe, as well as the near east, Mediterranean islands, part of the north coast of Africa, the Canary Islands and Madeira (Estoup *et al.* 1996; Widmer *et al.* 1998; Chittka *et al.* 2004). The British subspecies *B. terrestris audax* (Harris) was also introduced successfully to New Zealand from England in 1885 (Hopkins 1914). This was the extent of the global distribution for over 100 years. However, in 1987 the horticulture industry started using *B. terrestris* to improve pollination of greenhouse crops, particularly tomato *Solanum lycopersicum* L. (Velthuis and van Doorn 2006). Colonies of *B. terrestris* have subsequently been sold to growers of greenhouse tomatoes, not only within the natural distribution of *B. terrestris* and New Zealand, but also, in Iceland, Finland, Jordan, Saudi Arabia, Mexico, Chile, Argentina, Uruguay, South Africa, Taiwan, China, South Korea and Japan (Hingston *et al.* 2002; Australian Hydroponic & Greenhouse Association 2005; Velthuis and van Doorn 2006). *Bombus terrestris* has escaped from greenhouses and formed feral populations in Japan (http://www003.upp.so-net.ne.jp/consecol/english/maruhana/maruhana_info_eng.html; Matsumara *et al.* 2004), Chile (Ruz and Herrera 2001), Mexico and Uruguay (Australian Hydroponic & Greenhouse Association 2005).

Approval has not been given to import *B. terrestris* to Australia. However, two applications have been made to import *B. terrestris* to the Australian mainland for the pollination of greenhouse crops. The first of these (Goodwin and Steiner 1997) was rejected (Goodwin and Steiner 1999). However, another organization has recently reapplied (Australian Hydroponic & Greenhouse Association 2005) and this is currently being assessed by the Australian Department of Environment and Heritage.

Australia has a poor history of importing animals because it seemed like a good idea at the time, only to discover that it wasn't such a great idea after all (Low 1999). The lessons from this history are that it is important to assess carefully the risks associated with any proposed introduction of an exotic animal. Pest risk associated with introduction of non-native organisms has been defined as a function of: the risk of escaping from captivity; the risk of establishing outside captivity; the organism's potential geographic range; the organism's potential abundance within that range; and the organism's per capita effect on the ecosystem (Bigsby and Crequer 1998; Parker *et al.* 1999). This paper considers the risk of *B. terrestris* becoming a pest as a result of its proposed use inside greenhouses on the Australian mainland (Australian Hydroponic & Greenhouse Association 2005).

The risk of *Bombus terrestris* escaping from captivity

Colonies of *B. terrestris* can be started only by queens. Therefore, preventing queens escaping from hives could be an effective way of preventing a feral population from establishing. The likelihood of queens escaping from greenhouses can be reduced by adjusting the diameter of the hive's entrance to make it too small for queens to pass through while remaining large enough for workers to exit the hive and pollinate tomatoes (Thorp 2003; Australian Hydroponic & Greenhouse Association 2005; Ings *et al.* 2006). Unfortunately, this is not 100% effective at preventing queens from escaping from the hive into the greenhouse (Griffiths 2004; Australian Hydroponic & Greenhouse Association 2005). A representative of the bumblebee-production industry has stated 'On average, the pollinating life of a hive is some 8 to 10 weeks, at which time emerging bees are all males, sometimes followed by the emergence of new queens. Over 50% of hives within the greenhouse can expect to produce these queens. The diameter of the flight hole is such that it should prevent the egress of the larger-sized queens, but in practice, some queens and males escape into the glasshouse environment. Thus, whilst not all commercial hives will produce queens and the number per hive will be small, some can be expected to escape into the natural environment, where they will be fertilised by escaping males' (Griffiths 2004).

The risk of *Bombus terrestris* establishing outside captivity

Supporters of the introduction of *B. terrestris* to the Australian mainland have also stated that queens will escape from the greenhouses and produce feral colonies. Griffiths (2004) stated 'there is a risk that a limited number of fertilised queens will escape from commercial glasshouses into the environment. Whilst the overall numbers will be few, some feral colonies will establish'. Similarly, the previous submission to import *B. terrestris* to the Australian mainland stated 'While it is not the intention to establish feral populations, it is anticipated that improper use or accident could result in bumblebees establishing in the wild' (Goodwin and Steiner 1997). The establishment of feral populations of *B. terrestris* in Japan (Matsumara *et al.* 2004; http://www003.upp.so-net.ne.jp/consecol/english/maruhana/maru-hana_info_eng.html), Chile (Ruz and Herrera 2001), Mexico and Uruguay (Australian Hydroponic & Greenhouse Association 2005), as a result of escape from greenhouses, clearly supports their view.

The potential geographic range of *Bombus terrestris* on the Australian mainland

There is some uncertainty surrounding the area over which *B. terrestris* could establish on the Australian mainland. However, a consultant's report produced as part of the recent proposal to import *B. terrestris* to the Australian mainland indicates that this area is likely to be substantial. McClay (2005) produced two CLIMEX models to predict the potential geographic range of *B. terrestris* across mainland Australia. Model 1, based on the range of climates within the natural distribution of *B. terrestris*, predicted that *B. terrestris* could spread across most of Victoria, the eastern half of NSW, almost all the way up the Queensland coast, south-eastern SA, and a large area in south-western WA from Eyre to Geraldton. Model 2, based on the range of climates in the British Isles where subspecies *B. terrestris audax* occurs, predicted that this subspecies would be restricted to a smaller area comprising coastal and high elevation areas in Victoria and southern NSW south of Sydney, a small area in south-eastern SA, as well as high altitude areas around Armidale in northern NSW. However, this area, which is greater than the size of Tasmania, is the absolute minimum over which *B. terrestris audax* would spread (McClay 2005). In the absence of evidence that the natural range of *B. terrestris audax* is constrained by climate rather than the North Sea and English Channel, McClay (2005) concluded that *B. terrestris audax* 'could establish in broader areas of Australia, possibly approaching the limits of the potential distribution of *B. terrestris sensu lato*' as determined from Model 1.

The potential abundance of *Bombus terrestris* within its predicted range

The density at which *B. terrestris* will occur if it establishes on the Australian mainland is also uncertain. However, observations of *B. terrestris* in Tasmania suggest that it is capable of becoming a major component of flower visitor faunas within climatically suitable areas on the Australian mainland. *Bombus terrestris* can reproduce successfully in indigenous Australian vegetation. A colony excavated in a Tasmanian national park produced at least 304 new queens and 939 workers/drones (Hingston *et al.* 2006). *Bombus terrestris* also sometimes comprises large parts of flower visitor faunas in Tasmania. For example, it comprised 43% of visits to flowers of *Gompholobium huegelii* Benth. (Hingston and McQuillan 1999), up to 92% of flower visitors to *Eucalyptus ovata* Labill. (AB Hingston, SA Mallick and S Wotherspoon unpubl. data.), and up to 100% of flower visitors to Tree Lupin *Lupinus arboreus* Sims (Stout *et al.* 2002).

The per capita effect of *Bombus terrestris* on the ecosystem

Determining the effect that *B. terrestris* is having on the Tasmanian ecosystem will require a great deal more research. Potential harmful impacts that *B. terrestris* could have include: '(1) competition with native animals for nectar and/or pollen of native plants; (2) reduced seed production and/or altered gene flow in native plants; and (3) increased seed production in introduced weed species' (Hingston 2005). The potential for these three impacts to occur depends upon the foraging preferences of *B. terrestris* because the first two are dependent upon *B. terrestris* foraging on native plants and invading native vegetation while the third impact could result from foraging on introduced species of plants.

Proponents of the introduction of *B. terrestris* to the Australian mainland have consistently argued that *B. terrestris* causes little harm in Tasmania because it prefers to forage on introduced species of plants and rarely invades native vegetation (Goodwin and Steiner 1997; Carruthers 2003; Griffiths 2004; Australian Hydroponic & Greenhouse Association 2005). However, 'even if bumblebees do concentrate their foraging on introduced plants, they could still have serious impacts on native plants and the native animals that feed from their flowers if some introduced plants produce more seeds as a response to pollination services by bumblebees and consequently become more invasive and outcompete the native plants' (Hingston 2005). An example of this is the South African lily *Agapanthus praecox* Willd. subsp. *orientalis,* which was not listed as naturalised in the late 1990s in Tasmania (Rozefelds *et al.* 1999) but is now regarded as an environmental weed around Hobart and the Tasmanian coast (Connolly *et al.* 2004; Hingston *et al.* 2005). This apparent increase in invasiveness may have been caused by *B. terrestris* because it appears to be the major pollinator of *A. praecox* in Hobart (Hingston 2006b). *Bombus terrestris* is the most common visitor to the flowers of *A. praecox* in Hobart, contacts the stigma and anthers far more frequently than does the only other regular visitor, and carries significantly more pollen of *A. praecox* than does the only other regular visitor (Hingston 2006b). Similarly, *Rhododendron ponticum* L. was not recorded as naturalised in the late 1990s (Rozefelds *et al.* 1999). However, large numbers of seedlings have recently been seen at several locations in western Tasmania, just outside the Tasmanian Wilderness World Heritage Area (M Baker 2005 pers. comm. 9 Nov.). It is likely that *B. terrestris* has caused the naturalisation of *R. ponticum* because bumblebees are known to be major pollinators of *R. ponticum* in Europe (Mejías *et al.* 2002; Stout *et al.* 2006). Another invasive plant in Tasmania that may be benefiting from pollination services provided by *B. terrestris* is *Buddleia davidii* Franchet, which has also become more invasive since the arrival of *B. terrestris* (A Crane 2005 pers. comm. 14 Nov.). Because its stigma is situated 5-7 mm along a narrow tubular corolla (AB Hingston pers. obs., see also Webb *et al.* 1988), only animals with tongues of this length or more are likely to deposit pollen on the stigma. The proboscises of *B. terrestris* – queens 8-11 mm, (Brian 1954); drones 8.1 mm (Medler 1962); workers 6.9-9.3 mm (Prys-Jones and Corbet 1991) – are long enough to contact the stigma in almost all cases, whereas those of the only other common visitor to flowers of *B. davidii* in Tasmania, the Honey Bee *Apis mellifera* L. (5.3-7.2 mm, Ruttner *et al.* 1978), are probably less likely to contact the stigma.

It is also possible that *B. terrestris* is harming Tasmanian native fauna and flora directly, because the claims that *B. terrestris* prefers to forage on introduced species of plants and rarely invades native vegetation in Tasmania (Goodwin and Steiner 1997; Carruthers 2003; Griffiths 2004; Australian Hydroponic & Greenhouse Association 2005) are contrary to a large volume of peer-reviewed research (Hingston and McQuillan 1998a,b, 1999; Olsson *et al.* 2000; Hingston *et al.* 2002, 2004b, 2006; Hingston 2005, 2006a). The only study in Tasmania that considered the relative numbers of flowers of introduced and native plants in the study area while testing the foraging preferences of *B. terrestris* found that 'The numbers of bumblebees seen foraging per 1000 flowers did not differ significantly between introduced plants and Australian native plants, and the preferred food sources of bumblebees included flowers of both introduced and Australian native species' (Hingston 2005). Indeed, it was known 10 years ago that *B. terrestris* was foraging on a wide variety of native plants in several types of native vegetation near Hobart (Hingston and McQuillan 1998a). By five years ago, *B. terrestris* had been found in 'all of Tasmania's major (native) vegetation types, altitudes from sea level to 1260 m ASL, and the entire breadth of annual precipitation in the state' (Hingston *et al.* 2002). During the summer of 2004-2005 'More than 10 bumblebees were seen in one day at 153 locations in native vegetation, including 42 locations within 10 National Parks and 38 locations within the Tasmanian Wilderness World Heritage Area' (Hingston 2006a). Further evidence of the capacity of *B. terrestris* to invade

Tasmanian native vegetation and forage on native plants comes from the excavation of a nest in Maria Island National Park in May 2005. This colony produced at least 304 new queens and 939 workers/drones on a diet that appeared to comprise almost entirely native plants, because at least 95.3% of the pollen stores in the nest were from native plants, with 84.5% being from *Eucalyptus* (Hingston *et al.* 2006).

This capacity for *B. terrestris* to invade native vegetation and forage on native plants in Tasmania means that it is a potential competitor of a wide range of native animals. The foraging profile of *B. terrestris* in native vegetation near Hobart 'overlapped with those of all anthophilous insect families, all bee subgenera, and all species of nectarivorous birds which were encountered' (Hingston and McQuillan 1998a). At this stage there has been little research into the competitive effects of *B. terrestris* on Tasmanian fauna, although there is some evidence of *B. terrestris* competing with native bees. In the presence of *B. terrestris,* native megachilid bees visited fewer flowers per hour, fewer flowers per foraging bout, spent less time per flower, and spent less time foraging, which suggests that they were being displaced through resource competition (Hingston and McQuillan 1999). However, it is not known if this translates into lower reproductive output in the megachilid bees. Indeed, we almost certainly do not have a complete list of the species of bees that occur in Tasmania (Hingston 1998, 1999), let alone know what impact *B. terrestris* is having on them. Stronger evidence of competition from *B. terrestris* reducing reproductive output in a native animal comes from observations of *B. terrestris* foraging heavily on *Eucalyptus globulus* Labill. (Hingston 2002; Hingston *et al.* 2004a,b) and *E. ovata* Labill. (AB Hingston, SA Mallick and S Wotherspoon unpubl. data). Reduced food availability in these plants is likely to reduce reproductive success in the nationally endangered Swift Parrot *Lathamus discolor* (Shaw), because its breeding success is limited by the availability of nectar and pollen of these two species of tree (Swift Parrot Recovery Team 2001; Gartrell 2002; AB Hingston 2002–2006 unpubl. data). Comparisons of the amounts of nectar in bagged and exposed flowers of *E. ovata* in the outer Hobart suburb of Mt Nelson revealed that *B. terrestris* sometimes has a marked effect on the amount of nectar available to Swift Parrots, particularly at low ambient temperatures. On a warm day (17 Nov. 2002, maximum temperature 28.2°C), *B. terrestris* commenced foraging at 7.00 am and the amount of nectar in exposed flowers declined between 7.00 am and 8.00 am to less than half of that in bagged flowers. This decline can be attributed only to foraging by *B. terrestris* because the only other common visitors to the flowers, Honey Bees, did not start foraging until 9.00 am (AB Hingston, SA Mallick and S Wotherspoon unpubl. data). On a day that was too cold and showery for Honey Bees to forage (6 Dec. 2002, maximum temperature 12.8° C), *B. terrestris* foraged from *E. ovata* continuously from 6.00 am until 6.00 pm and comprised 92% of all flower visitors on that day. During this time, the amounts of nectar in exposed flowers remained low while those inside bags increased markedly (AB Hingston, SA Mallick and S Wotherspoon unpubl. data). Hence, *B. terrestris* appeared to consume all of the diurnal nectar production on this day, which would clearly reduce the amount available to Swift Parrots. Evidence that reproduction in Swift Parrots was limited by food availability in this situation comes from the fact that, although 120 Swift Parrots foraged predominantly on flowers of *E. ovata* throughout this breeding season at Mt Nelson, few chicks were fledged. Single fledglings were observed on only three occasions (4, 29 and 30 Dec. 2002), with the last of these observations being of a fledgling on the ground that was too weak to fly (AB Hingston 2002 unpubl. data). The capacity for *B. terrestris* to remove nectar from flowers at times when it is too cold for Honey Bees to forage (AB Hingston, SA Mallick and S Wotherspoon unpubl. data), suggests that *B. terrestris* could also reduce nectar availability to commercial Honey Bees. Indeed, Tasmanian apiarists appear to be very concerned about the threat that *B. terrestris* poses to their industry. I was invited to present a seminar at the Tasmanian Beekeepers' Association

AGM in 2005, and delegates were very worried about this threat.

By invading native vegetation and foraging on many species of native plants in Tasmania, *B. terrestris* could also affect seed production in native plants. However, few studies have investigated this. *Bombus terrestris* appears to be able to pollinate *Eucalyptus globulus,* although it is not very effective at this. Single visits to flowers by *B. terrestris* resulted in less than 10% as many seeds as did single visits by Swift Parrots (Hingston *et al.* 2004b). Hence, in situations where more effective pollinators such as Swift Parrots are scarce, *B. terrestris* might increase seed production. However, if *B. terrestris* displaces pollinators that were more effective, the net effect could be a decline in seed set. *Bombus terrestris* may also reduce seed production by displacing effective pollinators from flowers with tubular corollas that it robs of nectar. This involves *B. terrestris* biting holes through the bases of tubular corollas to access nectar, if the corolla tube is too long for *B. terrestris* to reach nectar by probing through the corolla throat, thereby avoiding contact with anthers and stigmas and not pollinating the flower. *Bombus terrestris* has been observed robbing the native species *Epacris impressa* Labill. (Hingston and McQuillan 1998b), *Richea scoparia* Hook. f. (Olsson *et al.* 2000), *R. dracophylla* R. Br., *Billardiera longiflora* Labill., and a *Correa* cultivar with tubular corollas in Tasmania (AB Hingston pers. obs.).

Conclusions

The introduction of *B. terrestris* to the Australian mainland for pollination of greenhouse crops poses a potential threat to Australia's biodiversity because *B. terrestris* is likely to escape from captivity and form feral populations in the wild across a large area, it forages on many species of native and introduced plants and has spread rapidly throughout all major native vegetation types in Tasmania, it is able to reduce the amounts of nectar available to other animals by foraging at lower temperatures than other bees, and the effectiveness of *B. terrestris* as a pollinator sometimes differs from that of other animals.

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Hybridisation and invertebrate hosts – two neglected aspects of pest plants in south-eastern Australia

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Abstract

Many of the threats to our native flora, including habitat destruction, weed infestations, rabbits, are glaringly obvious. Hybridisation between native and 'introduced' species and introduced plant species acting as hosts for introduced pests are two threats that are generally overlooked by the casual observer. Examples are given of these two threats to our native plants. The implications of hybridisation and introduced plants acting as hosts on the long-term survival of our natural heritage are discussed. (*The Victorian Naturalist*, **124** (2), 2007, 117-122)

Introduction

The impact of introduced plants in Australia has gained national attention of late, being ranked as one of the highest risks to both economic and biodiversity values. The Co-operative Research Centre (CRC) for Australian Weed Management estimates that the cost of weeds to agriculture alone is in the vicinity of $4 billion per year (CRC for Australian Weed Management 2003). This figure does not take into consideration the impact of weeds on natural ecosystems, the potential loss of biodiversity values or the impacts on human health, most notable on hay fever sufferers (CRC for Australian Weed Management 2003).

It is estimated that there are 2 700 naturalised plant species in Australia, many of which were deliberate introductions for agricultural or ornamental use (Muyt 2001). Three hundred and seventy of these species are now of critical importance

Fig. 1. *Pittosporum bicolor* (Left), *Pittosporum undulatum* (Right) and hybrid (Middle).